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September 8, 2000

ATTORNEY DOCKET NO. 7099-1267

Box PATENT APPLICATION
Assistant Commissioner for Patents
Washington, D.C. 20231

Re: New U.S. Patent Application
Title: METHOD AND SYSTEM FOR DEVELOPING OPTIMIZED SCHEDULES
Inventor(s): D. Günther, E. Johnson, L. Lettovský, and B. Smith

Sir:

We enclose the following papers for filing in the United States Patent and Trademark Office in connection with the above patent application.

1. Application - 27 pages, including 3 independent claim(s) and 17 claims total.

2. Appendix A, 1 page; and Appendix B, 6 pages.

3. Drawings - 7 sheets of informal drawings (Figures 1-7).

4. A check for $690 representing the filing fee.

This application is being filed under the provisions of 37 C.F.R. § 1.53(f). Applicant(s) await notification from the Patent and Trademark Office of the time set for filing the Declaration.

Please accord this application a serial number and filing date.

The Commissioner is hereby authorized to charge any additional filing fees due and any other fees due under 37 C.F.R. § 1.16 or § 1.17 during the pendency of this application to our Deposit Account No. 06-0916.

Respectfully submitted,

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Enclosures

Attorney Docket No. 07099-1267

UNITED STATES PATENT APPLICATION

OF

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FOR

METHOD AND SYSTEM FOR DEVELOPING OPTIMIZED SCHEDULES

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BACKGROUND OF THE INVENTION

A. Field of the Invention

This invention generally relates to methods and systems for developing optimized schedules and, more particularly, to methods and systems employed to develop optimized schedules in the transportation field, such as the commercial airline industry.

B. Description of the Related Art

Schedule optimization is the process of selecting an arrangement of resources to maximize a desired benefit. In the airline industry, this process involves the selection and arrangement of flights (or legs) into a schedule that maximizes airline profit.

FIG. 1 depicts the process currently employed for schedule optimization in the airline industry. Underlying the process, one or more schedulers 10 utilize a computer system to selectively run a pair of conventional applications known in the art as the airline profitability model (APM) and the fleet assignment model (FAM).

During initialization, the APM receives a current schedule 12 of flights, logit parameters 14, and marketing data 16. The current schedule 12 typically includes the arrival and departure times, and the equipment assignments for all flights of the host airline (HA), the airline seeking schedule optimization. The current schedule 12 generally also includes similar information for all other airlines (OAs). The logit parameters 14 represent well-known estimates for the level of importance that the public may place on various aspects of a flight, such as whether a flight is non-stop.

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The marketing data 16 typically includes the total demand for flights in various markets.

Thereafter, the APM performs a conventional base run 18 on the input data to produce APM data 20. Among the APM data 20 produced are cost, demand, and revenue estimates for the current schedule 12 on a per flight, per itinerary, or per market basis, as desired. As used herein, a flight is a non-stop service in between an origination and a destination (the pair defining a market), while an itinerary is one or more interconnected flights.

The scheduler 10 then reviews the APM data 20 to identify changes that may improve the HA's schedule. Such changes may include adding a flight, canceling a flight, shifting the departure time of a flight, altering the frequency of a flight, and the like. Assuming that a potentially desirable change is identified, the scheduler 10 creates a proposed schedule 22 by manually incorporating the change into the current schedule 12. This step is no small matter, for nearly any change to a schedule must be made under the inherent constraints imposed by the rest of the schedule. For example, adding a new flight may mean that an existing flight needs to be canceled, which could also impact other flights in the schedule.

Assuming that the scheduler 10 is able to incorporate the change, the scheduler 10 directs the APM to perform a conventional incremental run 24 on the proposed schedule 22. The APM data 26 output includes cost, demand, and revenue estimates for the proposed schedule 22. This output is then fed to a conventional fleet assignment model (FAM) 28, which produces a fleeted schedule 30 consistent with

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the APM data 26. The fleeted schedule 30 is then run through the APM to produce APM data 20 indicating cost, demand, and revenue based on the fleeting of the proposed schedule 22. At this point, the scheduler 10 compares the APM data 20 just produced with that generated from the original schedule 12 to see if the change incorporated into the proposed schedule 22 increased HA profit. Profitable changes are ultimately made part of a final schedule 32.

However, as is often the case, several iterations of this time-consuming process are required to confirm the discovery of even a single profitable change to the schedule. Another significant issue facing the scheduler 10 is that there are so many changes that could logically be considered for entry into the schedule. As such, it is desirable to be able to incorporate multiple changes into the proposed schedule 22 for consideration.

Unfortunately, as those skilled in the art appreciate, the nature of conventional APMs and FAMs limits the number of possible changes that may be considered at one time. Specifically, running an APM on a "heavily overbuilt schedule" (i.e., a schedule with several proposed changes incorporated therein) produces inaccurate demand estimates. Generally, this inaccuracy increases as the difference between the proposed schedule 22 and the fleeted schedule 30 becomes larger relative to the overall size of the fleeted schedule 30. Consequently, only small incremental changes to a proposed schedule 22 can be evaluated with any reasonable degree of accuracy. Moreover, those skilled in the art know that the FAM is similarly limited to fleeting proposed schedules 22 with relatively few incorporated changes.

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In summary, the present process is time and resource inefficient based on the combined effects of having to: (1) manually identify and incorporate proposed changes into a schedule; and 2) limit to relatively few the number of proposed changes for testing in a single run of the APM and FAM models. There is therefore a need for a method and system to overcome these and other limitations of the prior art approach.

SUMMARY OF THE INVENTION

Accordingly, systems and methods consistent with the present invention substantially obviate one or more of the problems due to limitations, shortcomings, and disadvantages of the related art by automating the schedule generation process.

In accordance with the present invention, as embodied and broadly described herein, a method for optimizing a schedule of legs employed in transporting objects between geographic markets is delineated. The method includes the steps of: (1) identifying a set of itineraries for serving each market in a set of markets, where each itinerary comprises one or more legs; (2) generating a set of market plans for each market, where each market plan comprises a modified set of the itineraries for the market; (3) determining the profitability of each market plan; and (4) selecting from the set of market plans a subset optimizing overall profit of the schedule.

Both the foregoing general description and the following detailed description are exemplary and explanatory only, and merely provide further explanation of the claimed invention.

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BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate an embodiment of the invention and, together with the description, serve to explain the advantages and principles of the invention. In the drawings,

FIG. 1 is a schematic block diagram of a prior art process for schedule generation;

FIG. 2 is a schematic block diagram showing aspects of the present invention;

FIG. 3 is a schematic block diagram depicting a hardware configuration for employing the present invention;

FIG. 4 is a flowchart depicting aspects of the process for schedule generation;

FIG. 5 is a flowchart depicting aspects of the process of FIG. 4;

FIGS. 6A-C is a schematic representation depicting aspects of the process of FIG. 4; and

FIG. 7 flowchart depicting aspects of the process of FIG. 4.

DETAILED DESCRIPTION

Reference will now be made in detail to an implementation of the present invention as illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings and the following description to refer to the same or like parts.

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Overview

FIG. 2 is a high-level view of the process of the present invention. To begin, the scheduler 10 inputs data 36 identifying new flights (or services), and suggested equipment for use by such flights, which is automatically considered for entry into a final schedule 32. Employing the current schedule 12, the new flights and equipment data 36, and a group of scheduler-selected control parameters 34, a comprehensive set of market plans are generated for each market of interest in step 38. As will be discussed in detail below, a market plan is an automatically-generated list of itineraries for serving a city-pair called a market.

In step 40, an APM is conventionally employed to evaluate the market plans and produce estimated cost, demand, and revenue for each market plan. In so doing, the APM utilizes logit parameters 14 set in a well-known manner by the scheduler 10, the control parameters 34, and marketing data 16. In step 42, a conventional mathematical program solver, pre-programmed with a mixed integer program (MIP), considers the control parameters 34 and all of the market plans to select an optimal subset of market plans. This selection is made according to the MIP's predefined problem and constraints such that the selected subset of market plans produces an optimized overall profit for the resulting proposed schedule 44.

Using the proposed schedule 44, a new set of market plans may be generated in step 38, and if so, the sequence shown in the dashed-line box of FIG. 2 is repeated until a predefined termination condition is met. Specifically, the scheduler 10 may set a control parameter 34 to limit the number of iterations to a fixed number count.

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Alternatively, the scheduler 10 may set a threshold increase in the overall estimated profit between subsequent iterations. Below this threshold, the iterations will automatically terminate.

In either case, a proposed schedule 44 identifying a set of optimum market plans for each market is ultimately sent to the FAM 28, which produces in a conventional manner a fleeted schedule 30. Thereafter, a conventional APM base run 18 is performed on the optimized fleet schedule 30 to produce APM data for scheduler review.

Computer Architecture

FIG. 3 illustrates a distributed processing system 46 which can be used to implement the present invention. In FIG. 3, the distributed processing system 46 contains three independent and heterogeneous platforms 48, 50, and 52 connected in a network configuration represented by the network cloud 54. The composition and protocol of the network configuration represented in FIG. 3 by the cloud 54 is not important as long as it allows for communication of the information between platforms 48, 50 and 52. In addition, the use of just three platforms is merely for illustration and does not limit the present invention to the use of a particular number of platforms. Further, the specific network architecture is not crucial to this invention. For example, another network architecture that could be used in accordance with this invention would employ one platform as a network controller to which all the other platforms would be connected. Additionally, one could employ a

single independent platform, and in any event, one or more schedulers 10 would oversee the schedule generation process from one or more of the platforms.

In the implementation of distributed processing system 46, platforms 48, 50 and 52 each include a processor 56, 58, and 60 respectively, and a memory, 62, 64, and 66, respectively. Included within each processor 56, 58, and 60, are applications 68, 70, and 72, respectively, and operating systems 74, 76, and 78, respectively.

Applications 68, 70, and 72 can be programs that are either previously written and modified to work with the present invention, or that are conventionally written to take advantage of the services offered by the present invention. Applications 68, 70, and 72 invoke operations to be performed in accordance with this invention.

Operating systems 74, 76, and 78 are standard operating systems tied to the corresponding processors 56, 58, and 60, respectively. The platforms 48, 50, and 52 can be heterogenous or homogenous.

Memories 62, 64, and 66 serve several functions, such as general storage for the associated platform. Another function is to store applications 68, 70, and 72, and operating systems 74, 76, and 78 before execution by the respective processor 56, 58, and 60. In addition, portions of memories 62, 64, and 66 may constitute shared memory available to all of the platforms 48, 50, and 52 in network 46.

Leg Generation Phase

The primary purpose of the leg generation phase shown in FIG. 4 is to create an overbuilt host schedule (OHS). The OHS is referred to as "overbuilt" because it

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includes not only HA legs that are actually scheduled for flight, but also a number of HA legs not presently scheduled for HA flight, but which may be subsequently incorporated into the HA schedule if deemed appropriate. Employing the OHS in the schedule generation process, as discussed below, increases the number of proposed schedule changes that may be efficiently considered above that previously possible.

In step 80, the provided input data includes: (1) an input schedule identifying all HA legs scheduled for flight, and which may include for each leg an origination, a destination, departure and arrival times, and equipment assigned to the leg; (2) a list of new leg(s), if desired, for consideration as entries to the schedule, and which may each include identification of desired origination, destination, arrival and departure times, and equipment assigned to the leg (or a group of potential equipment types from which one may be selected); (3) a list of curfew times for each airport, representing times that aircraft arrival or departure is not permitted at a specified airport; (4) a list of HA hub stations, meaning airports heavily serviced by the HA; (5) a list of time points, each representing a midpoint of a different specified time period (called a complex) during which HA flights may arrive or depart at a particular airport; (6) a list of one or more arrival time bandwidths, the appropriate bandwidth being applied before and after a specified arrival time point to define an arrival complex for a specified airport; and (7) a list of one or more departure time bandwidths, the appropriate bandwidth being applied before and after a specified departure time point to define a departure complex for a specified airport.

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In step 82, the input schedule, including the scheduled HA legs, and the list of new leg(s), if any, are first organized and then processed for leg generation. The organization process is represented by the sequence shown in FIG. 5, and the leg generation scheme is represented by FIGs 6A-C, and their accompanying description below.

Turning first to FIG. 5, its sequence creates a list of all legs in the input schedule, to identify which of the previously-specified arrival and departure complexes of the hub stations are served by one or more HA leg. Specifically, in step 86 each leg of the input schedule is read in turn, and if it is determined in step 88 that the origination and destination pair of the subject leg is not already on the specified list, then the leg's origination and destination pair is added to the list in step 90. Assuming that a leg under consideration is part of the specified list, at step 92 it is determined whether the leg's departure station is a HA hub station. If so, in step 94 the closest departure complex is identified to see if the leg's departure time falls within the departure complex's time window. The list is then updated to indicate whether or not the leg's departure time falls within its closest departure complex time window. If in step 92, it is determined that the leg's departure station is not a HA hub station, or after step 94, a similar determination is made concerning the leg's arrival station in steps 96 and 98.

Specifically, in step 96 it is determined whether the leg's arrival station is a HA hub station. If not, the next leg in the input schedule is read at step 86. However, if the present leg's arrival station is a HA hub station, then in step 98 the closest

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arrival complex is identified to see if the leg's arrival time falls within the arrival complex's time window. The list is then updated to indicate whether or not the leg's arrival time falls within its closest arrival complex time window. The sequence of steps 86-98 is repeated to allocate to the specified list each unique origination and destination pair from the legs of the input schedule, as well as whether a leg serves a HA hub, and whether a leg serves a particular departure or arrival time complex.

After reading the entire input schedule, additional legs are automatically generated for all services that are contained in the input schedule that either start or end at a HA hub station. As used herein, the term, "service," means one or more flights traveling at different times within a planning horizon (i.e., a scheduler-selected time period) between a market's city pair (e.g., a HA's flight(s) from Washington, D.C. to New York over a day). The automatic generation of additional legs is demonstrated by the example sequence shown in FIGs. 6A-C.

Specifically, FIG. 6A represents a HA departure hub 100, including a number of HA departure complexes 104a-c; a HA arrival hub 102, including a number of HA arrival hubs 106a-c; and a pair of HA legs 108a and 108b. The HA legs 108a and 108b represent HA legs from the input schedule, from the list of new leg(s), if any, or from a combination of both. In any event, the legs 108a and 108b serve (i.e., intersect) complexes 104a, 104c, and 106c. This means that complexes 104b, 106a, and 106b are not served, as shown in FIG 6A.

Additional legs are then generated to cover the unserved complexes, as best represented by FIG. 6B. A copy of an existing leg (e.g., 108a or 108b) in the service

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is generally copied, and then employed with each of the unserved complexes 104b, 106a, and 106b. Out of convenience, a copied leg is merged with the midpoint of each of the unserved complexes. For example, note that added legs 108c, 108d, and 108e intersect the respective midpoints of their corresponding complexes 106a, 104b, and 106b. It is noted that using for additional legs a copy of an existing leg in a service, as well as merging the new leg with the midpoint of an unserved complex, are merely exemplary, as other schemes could be employed, if desired.

Referring to FIG. 6C, a curfew time 110 is added to the arrival hub 102, meaning that aircraft arrival is prohibited during this time period. Consequently, two of the three additional legs (i.e., 108d and 108e) generated in FIG. 6B are suppressed by the curfew time 110. The resulting legs for service in the HA market defined by departure hub 100 and arrival hub 102 are the two originally-generated legs 108a and 108b, and the newly generated leg 108c.

At the close of the leg generation phase, as best seen in FIG. 4, the OHS is provided in step 84 to a conventional APM to generate itineraries at step 112 in a well-known manner. Here, other airline (OA) schedules are also employed with the OHS to produce itineraries encompassing both the HA and OAs.

Initialization Phase

During the initialization phase, various data are assembled and input for use in the improvement phase, discussed below. At step 114, the APM-generated itineraries for the HA and OA are assembled for input at step 116.

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Among the data read in step 116 are the following inputs provided in step 118: (1) the OHS which may be used to, among other purposes, distinguish between legs that are actually scheduled for flight in the input schedule of step 80, and additionally-generated legs that are not presently scheduled for flight; (2) logit parameters comprising a well-known group of logit-based parameters employed by an APM; (3) marketing data typically provided for conventional APM operation, including for example: fares offered in each market, demand for each market, time of day curves, and the like; (4) equipment data routinely used by a conventional APM, including by way of example: the time to turn around from arrival to departure for each equipment type (turn-around time), the number of planes of a given type in the HA fleet (plane count), the duration that the HA plane count can serve within a given period of time (block time), HA aircraft types, and HA seat capacity for each equipment type, and the like.

Also input at step 116 are various control parameters employed during the improvement phase. Among the control parameters that are input are the following: (1) minimum origin point of presence (OOP), meaning the minimum total number of HA departures at a specified station for a specified time period; (2) maximum OOP, meaning the maximum total number of HA departures at a specified station for a specified time period; (3) threshold OPP, which if set/(not set), means that the OPP must/(may or may not) fall between the specified minimum and maximum OPPs; (4) minimum service frequency, meaning the minimum service frequency (i.e., number of flights over a specified time period) for a specified service; (5) maximum service

frequency, meaning the maximum service frequency for a specified service; (6) threshold service frequency, which if set/(not set), means that the service frequency must/(may or may not) fall between the specified minimum and maximum service frequencies; (7) required markets and legs; and (8) termination condition(s), which are discussed below for use in determining the number of iterations to be performed in the improvement phase.

At the conclusion of the initialization phase, a HA equipment count and block time are obtained in step 120, for subsequent use in the improvement phase. Step 120 may be performed by programming a conventional mathematical solver program with a mixed integer program (MIP) with constraints defining a suitable time-space network, such as the MIP shown in attached Appendix A. This MIP example looks at the scheduled HA legs from the input schedule to determine when and where HA aircraft go into and out of service. Also determined are how many HA flight hours are available, as well as a plane count by equipment type.

Alternatively, the scheduler 10 may input such data directly into the system, without employing the above-noted MIP, or another one similar thereto. Moreover, the scheduler 10 may wish to input such data based on a hypothetical HA fleet, irrespective of the actual HA input schedule.

Improvement Phase (Market Plan Generation)

At the outset, it is noted that the name of this section, "Improvement Phase," is not necessarily intended to delineate the metes and bounds of the invention.

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At step 122, a number of market plans are generated in a process represented by the sequence shown in FIG. 7. In step 124, a first HA market is taken up for consideration, for example the Dallas to Seattle market. In step 126, each itinerary that does or could serve the subject market is known. Here, assume that three itineraries serve or could serve the market (e.g., I1 = Dallas to Seattle, I2 = Dallas to San Francisco to Seattle, and I3 = Dallas to Phoenix to Seattle). Then, itinerary I1 is taken up, and it is determined in step 128 whether I1 has a HA leg. If no HA leg is included in I1, which consists of a single leg here, the next itinerary I2 would be taken up for consideration.

Assuming that the leg forming I1 is a HA leg, a first market plan is initialized in step 130. In step 132, the status of itinerary I1 is flipped, and the status of the remaining itineraries I2 and I3 is not changed. For instance, if the baseline set of itineraries for serving the market was: itinerary I1 (flown) and itineraries I2 and I3 (not flown), then the first market plan would consist of flipping itinerary I1 (i.e., from flown to not flown) and leaving itineraries I2 and I3 as not flown. In step 134, conventional elapsed time pruning is performed on the active (or flown) itineraries in the first market plan, of which there are none. In step 136, all HA legs are identified in the active itineraries, of which there are none here. In step 138, it is determined whether a previously-stored market plan uses the same set of HA legs as determined in step 136. If so, the market plan is not stored, and if not, the market plan is stored in step 140. Here, since only one market plan has been considered thus far, the first

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market plan is stored. However, the system may be set up to not store inactive market plans, as here, to save computing resources.

Having considered the first market plan, the process returns to step 126 to consider the next itinerary I2. Again, it is determined in step 128 whether I2 has a HA leg. If no HA leg is included in I2, the next itinerary I3 would be taken up for consideration.

Assuming that I2 includes a HA leg, a second market plan is initialized in step 130. In step 132, the status of itinerary I2 is flipped, and the status of the remaining itineraries I1 and I3 are not changed. Continuing with the example, this means that in the second market plan itineraries I1 and I2 would be flown (having flipped I2), while itinerary I3 would not be flown. In step 134, conventional elapsed time pruning is performed on the active (or flown) itineraries in the second market plan. Specifically, if one or more legs are shared between active itineraries, then the itinerary that is shortest in duration will remain active, while the remaining active itineraries in this comparison are turned off. In step 136, all HA legs are identified in the active itineraries of the second market plan (here, itineraries I1 and I2). In step 138, it is determined whether a previously-stored market plan uses the same set of HA legs as determined in step 136. If so, the market plan is not stored, and if not, the market plan is stored.

Having stored the second market plan in step 140, the process returns to step 126 to consider the next itinerary I3. Again, it is determined in step 128 whether I3

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has a HA leg. If no HA leg is included in I3, the next market and its assigned itineraries would be taken up for consideration.

Assuming that I3 includes a HA leg, a third market plan is initialized in step 130. In step 132, the status of itinerary I3 is flipped, and the status of the remaining itineraries I1 and I2 are not changed. Continuing with the example, this means that in the third market plan itineraries I1 and I3 would be flown (having flipped I3), while itinerary I2 would not be flown. In step 134, conventional elapsed time pruning is performed on the active (or flown) itineraries in the third market plan. In step 136, all HA legs are identified in the active itineraries of the third market plan (here, itineraries I1 and I3). In step 138, it is determined whether a previously-stored market plan uses the same set of HA legs as determined in step 136. If so, the market plan is not stored, and if not, the market plan is stored.

Improvement Phase (Market Plan Evaluation)

Returning to FIG. 4, after completing step 122, a number of market plans have been generated for all HA markets, each market plan representing a different alternative for serving a respective HA market.

In step 142, an APM is conventionally employed to evaluate each market plan, one at a time. Specifically, the APM estimates for each market plan include: (1) anticipated revenue, (2) spill cost for each leg, (3) fixed and variable costs for each leg, (4) demand for each leg, (5) cost to operate each airport, and (6) the cost to

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operate each flight. This data is subsequently utilized to help select an appropriate subset of market plans for the schedule.

Improvement Phase (Market Plan Selection)

Still referring to FIG. 4, at step 144, a conventional program solver is employed to formulate and solve a mixed integer program (MIP), which is utilized to select a subset of market plans that is consistent across all markets and maximizes overall HA profit. Appendix B sets forth such a MIP, and includes the MIP's equations, a description of the MIP's variables, and a description of the MIP's objective function and constraints. Those with skill in the art understand the operation of the disclosed MIP to perform the recited function, and further appreciate that various other MIPs may be employed to perform similar market plan selection functions, if desired. Incorporated herein by reference is an additional resource concerning MIPs entitled *Integer and Combinatorial Optimization*, authored by G.L. Nemhauser and L.A. Wolsey, and published by John Wiley & Sons, Inc., 1988.

In selecting market plans to serve the various markets, the MIP may assign to each market plan a separate valuation, representing a percentage of the estimated full demand (or number of potential passengers) that could be served by the subject market plan. In this regard, the MIP may be formulated to provide fractional valuations for the market plans, meaning that a given market plan having a fractional valuation is anticipate to cover a fractional portion of its potential full demand.

By way of example, a market plan estimated to have a demand of 100 passengers and having an assigned valuation of 1.0 would be operated, and in so doing, anticipated to cover all 100 passengers (the market plan's full demand). Any other market plans in the same market would have assigned market plan valuations of zero, as the MIP constrains the sum of market plan valuations in the same market to one; however, the MIP may alternatively restrict this sum to any fixed value, including one, within a suitable range of values. Market plans with valuations of zero are not operated.

In contrast, a market plan with a non-zero valuation of less than one is still operated, but it may not be anticipated to cover its full potential demand. For instance, in a market with two market plans MP1 and MP2, assume that the full estimated demand is 100 passengers for MP1, and 200 passengers for MP2. If the MIP assigns fractional valuations to the market plans MP1 and MP2 of 0.4 and 0.6, respectively, this means that both market plans MP1 and MP2 will be operated; however, the estimated demand serviced by each market plan would be 40 passengers (0.4 x 100 passengers) and 120 passengers (0.6 x 200 passengers), respectively.

As suggested by the example above, assignment of fractional valuations for the market plans permits having more than one market plan serving a particular market. This may be desirable to increase offered services in suitable markets (e.g., where demand is high). However, increasing offered services in one market, may impact the ability to serve other markets, as an airline has finite resources to

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implement its schedule. The MIP takes this into account in selecting a subset of market plans intended to optimize overall profitability of the schedule.

Improvement Phase (Schedule Evaluation)

In step 146, an APM is conventionally employed to evaluate the subset of market plans selected by the MIP, recalling that the subset of selected market plans forms a proposed, optimum schedule. As is known in the art, the APM provides cost, revenue, and demand estimates for subsequent evaluation.

In step 148, termination conditions are evaluated to see if additional iterations of steps 122, and 142-148 are to be executed. Specifically, the scheduler 10 may have input at step 116 a value establishing a fixed number of such iterations to be performed. Alternatively, the scheduler 10 may have input a threshold overall profitability value above which subsequent computations of step 146 must stay in order to perform subsequent iterations. Additional alternative termination criteria may be employed, as desired. Assuming that additional iterations are to be performed, then the selected schedule from step 144 is used as an input to step 122 to generate new market plans.

In step 150, the scheduler 10 has the option to change certain desired boundary conditions in step 154. If the scheduler 10 decides not to relax boundary conditions, a new optimized schedule and related statistics are provided at step 152, which are then processed by the FAM 28 and APM 18 in FIG. 2 to complete fleet

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scheduling of the optimized schedule, and to produce final APM estimations for the schedule.

Of course, if the scheduler 10 opted to change boundary conditions in step 150, then new boundaries conditions are input, as desired. For example, the scheduler 10 may want to change the minimum or maximum permissible service frequency, or OPP, for subsequent evaluation employing the process, as discussed above.

The foregoing description of an implementation of the invention has been presented for purposes of illustration and description. It is not exhaustive and does not limit the invention to the precise form disclosed. Modifications and variations are possible in light of the above teachings or may be acquired from practicing of the invention. For example, the manner of modifying a set of itineraries to form market plans could be varied, as desired. Additionally, while the general field of use for the invention has been described as the airline industry, it could similarly be employed in other transportation industries. The scope of the invention is defined by the claims and their equivalents.

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WHAT IS CLAIMED IS:

1. A computer implemented method for optimizing a schedule of legs employed in transporting objects between geographic markets, the method comprising the steps of:

   a) identifying a set of itineraries for serving each market in a set of markets, each itinerary comprising one or more legs;

   b) generating a set of market plans for each market, each market plan comprising a modified set of the itineraries for the market;

   c) determining the profitability of each market plan; and

   d) selecting from the set of market plans a subset optimizing overall profit of the schedule.

2. The method of claim 1, wherein the generating step includes the substeps of:

   a) changing a status parameter of one of the itineraries in the set of itineraries while leaving the status parameters for the remaining itineraries unchanged; and

   b) repeating said changing step for each itinerary in the set.

3. The method of claim 1, wherein market plans are generated utilizing itineraries including at least one leg from a specified service provider.

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4. The method of claim 1, wherein the determining step employs a profitability model.

5. The method of claim 1, wherein the selecting step employs a mixed integer program to select the subset of market plans to maximize overall profit of the schedule.

6. The method of claim 1, further including the step of evaluating a termination condition to determine whether additional market plans will be generated using the subset of market plans.

7. The method of claim 1, wherein the identifying step includes the substep of generating the set of itineraries based on at least scheduled legs and automatically-generated hypothetical legs of a specified service provider.

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8. A system including one or more computers executing applications for optimizing a schedule of legs employed in transporting objects between geographic markets, the system comprising:

a) a component configured to identify a set of itineraries for serving each market in a set of markets, each itinerary comprising one or more legs;

b) a component configured to generate a set of market plans for each market, each market plan comprising a modified set of the itineraries for the market;

c) a profitability model configured to determine the profitability of each market plan; and

d) a mixed integer program configured to select from the set of market plans a subset optimizing overall profit of the schedule.

9. The system of claim 8, wherein the component configured to generate a set of market plans is further configured to:

a) change a status parameter of one of the itineraries in the set of itineraries while leaving the status parameters for the remaining itineraries unchanged; and

b) repeat said changing step for each itinerary in the set.

10. The system of claim 8, wherein market plans are generated utilizing itineraries including at least one leg from a specified service provider.

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11. A computer program product having computer readable instructions for programming a computer to optimize a schedule of legs employed in transporting objects between geographic markets, by performing the steps of:

a) identifying a set of itineraries for serving each market in a set of markets, each itinerary comprising one or more legs;

b) generating a set of market plans for each market, each market plan comprising a modified set of the itineraries for the market;

c) determining the profitability of each market plan; and

d) selecting from the set of market plans a subset optimizing overall profit of the schedule.

12. The computer program product of claim 11, wherein the generating step includes the substeps of:

a) changing a status parameter of one of the itineraries in the set of itineraries while leaving the status parameters for the remaining itineraries unchanged; and

b) repeating said changing step for each itinerary in the set.

13. The computer program product of claim 11, wherein market plans are generated utilizing itineraries including at least one leg from a specified service provider.

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14. The computer program product of claim 11, wherein the determining step employs a profitability model.

15. The computer program product of claim 11, wherein the selecting step employs a mixed integer program to select the subset of market plans to maximize overall profit of the schedule.

16. The computer program product of claim 11, further including the step of evaluating a termination condition to determine whether additional market plans will be generated using the subset of market plans.

17. The computer program product of claim 11, wherein the identifying step includes the substep of generating the set of itineraries based on at least scheduled legs and automatically-generated hypothetical legs of a specified service provider.

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ABSTRACT

In accordance with the present invention a process is provided for optimizing a schedule of legs employed in transporting objects between geographic markets. The process identifies a set of itineraries for serving a set of markets, and then generates a set of market plans for each market. Each market plan comprises a modified set of the itineraries for the market. The profitability of each market plan is then determined, and a selection is made from the set of market plans of a subset thereof that optimizes overall profit of the schedule.

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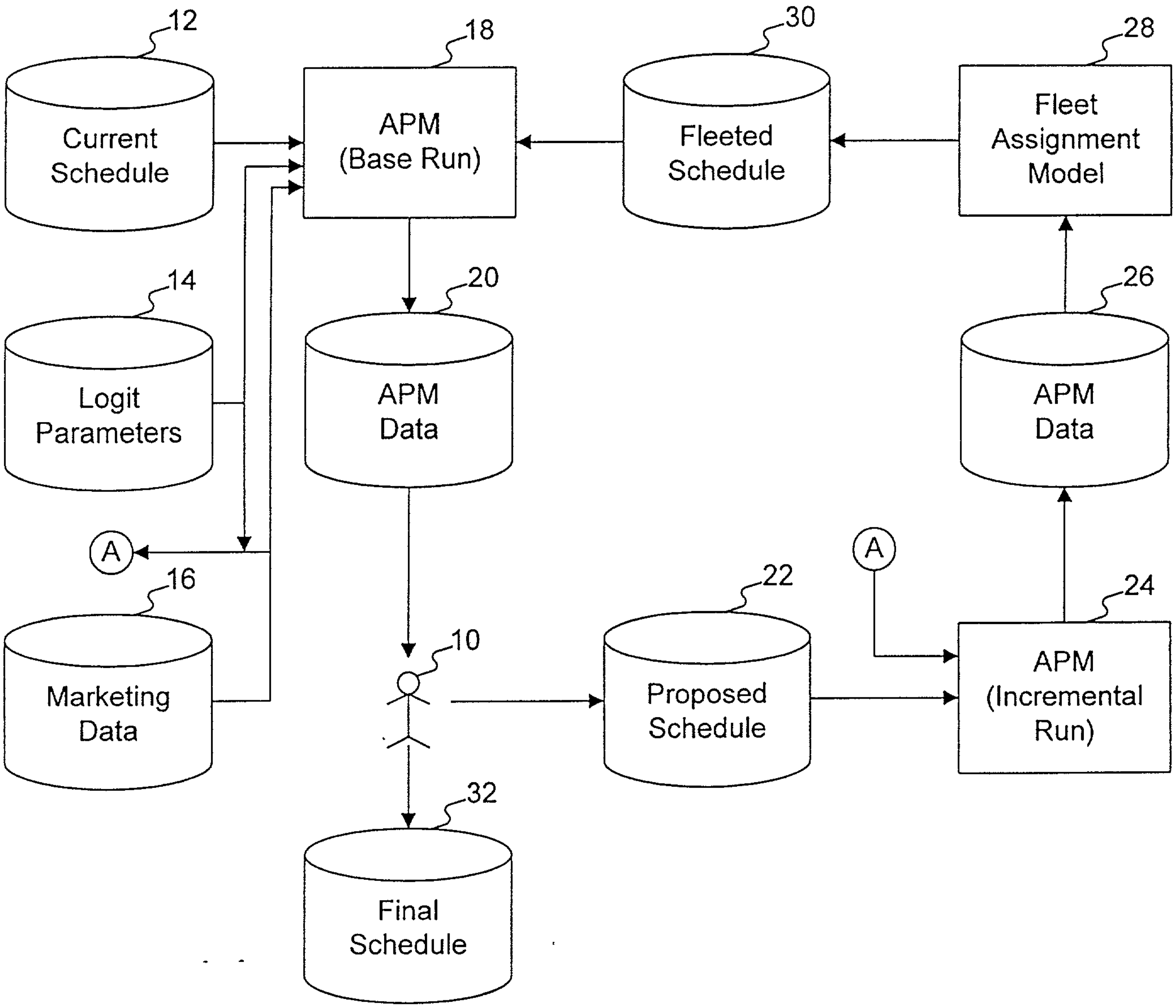

FIG. 1 (Prior Art)

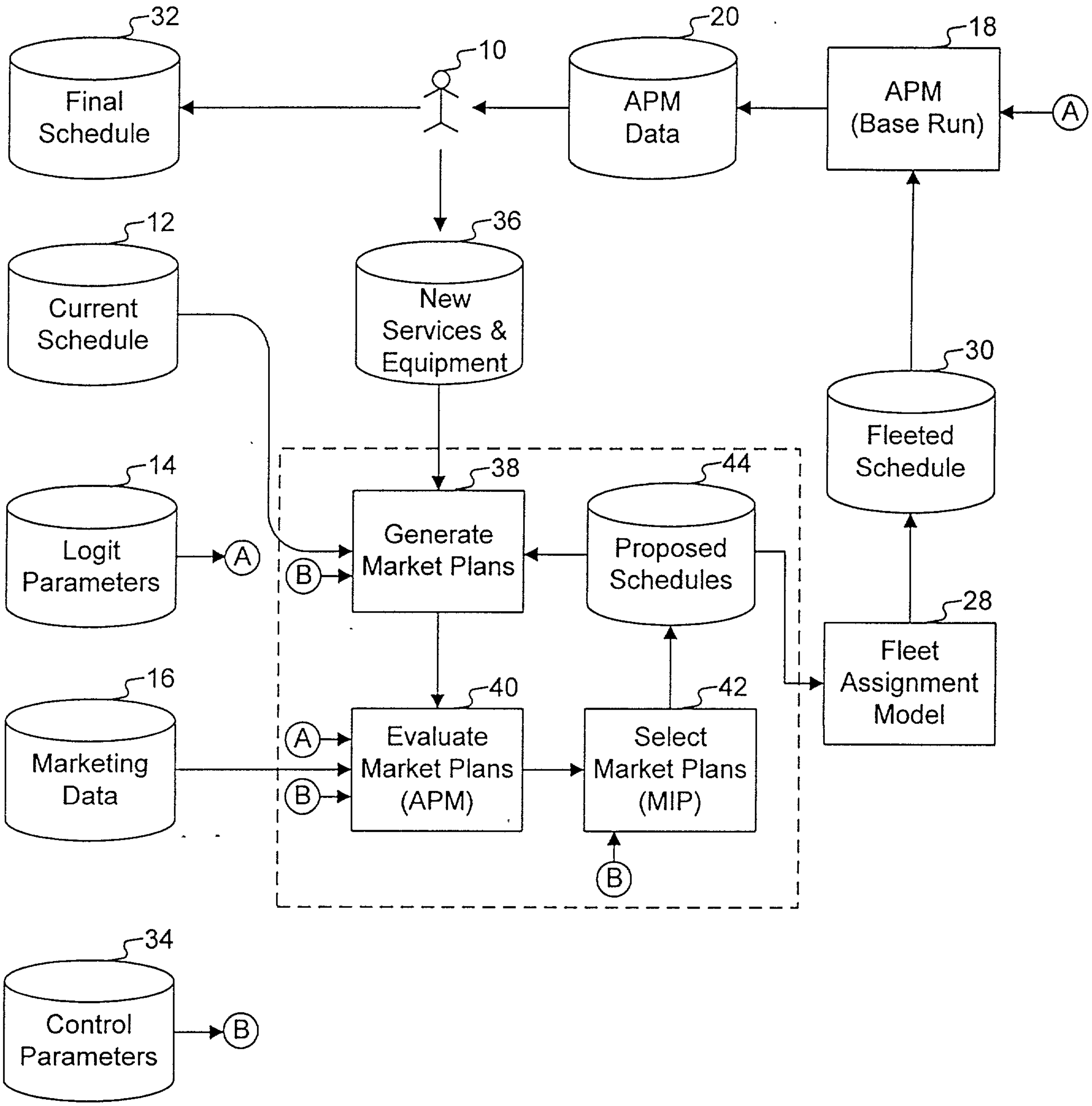
32
Final Schedule
10
20
APM Data
18
APM (Base Run)
A
12
Current Schedule
36
New Services & Equipment
14
Logit Parameters
A
38
Generate Market Plans
B
44
Proposed Schedules
30
Fleeted Schedule
28
Fleet Assignment Model
16
Marketing Data
40
Evaluate Market Plans (APM)
A
B
42
Select Market Plans (MIP)
B
34
Control Parameters
B

FIG. 2

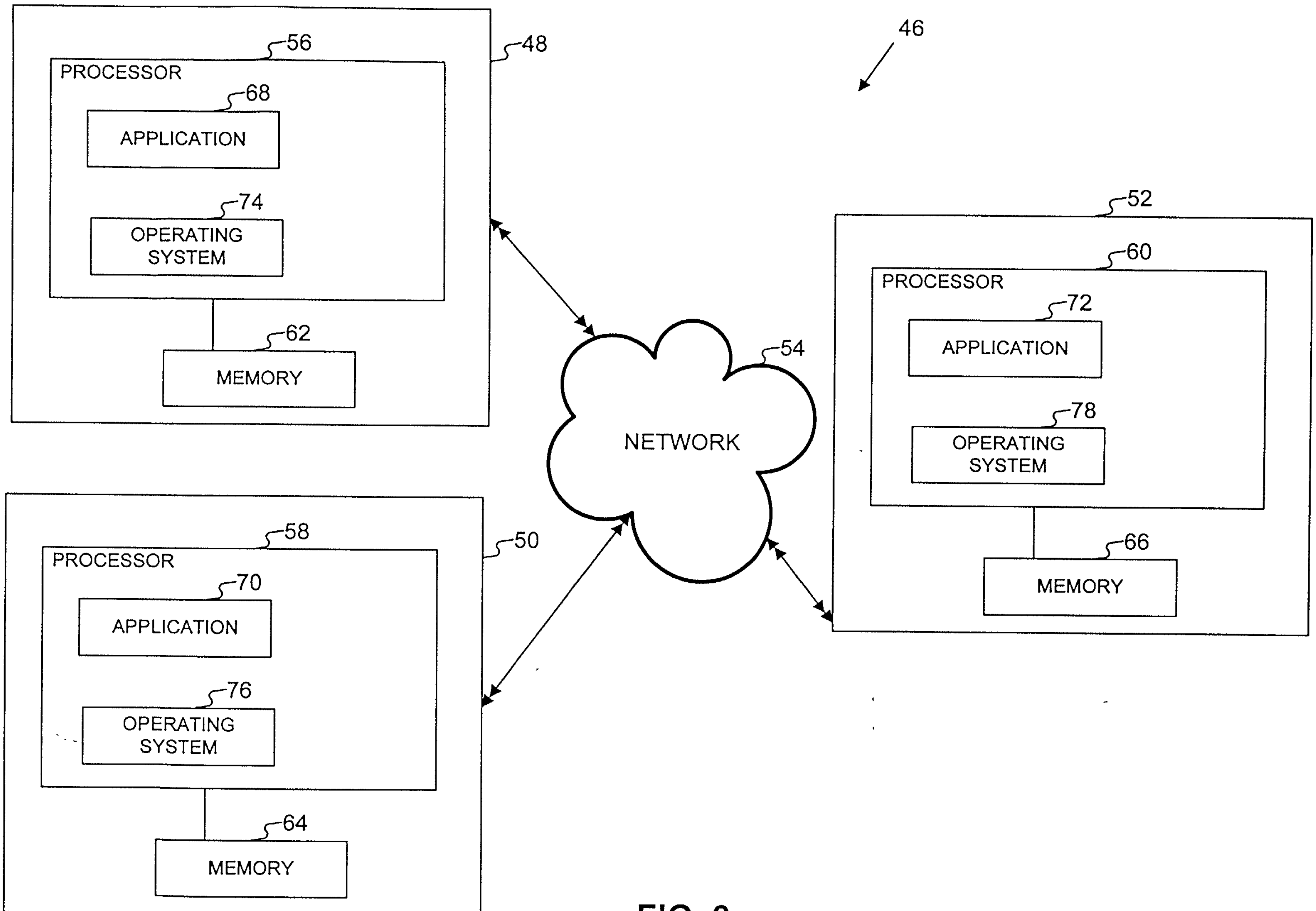

FIG. 3

09658866 .090800

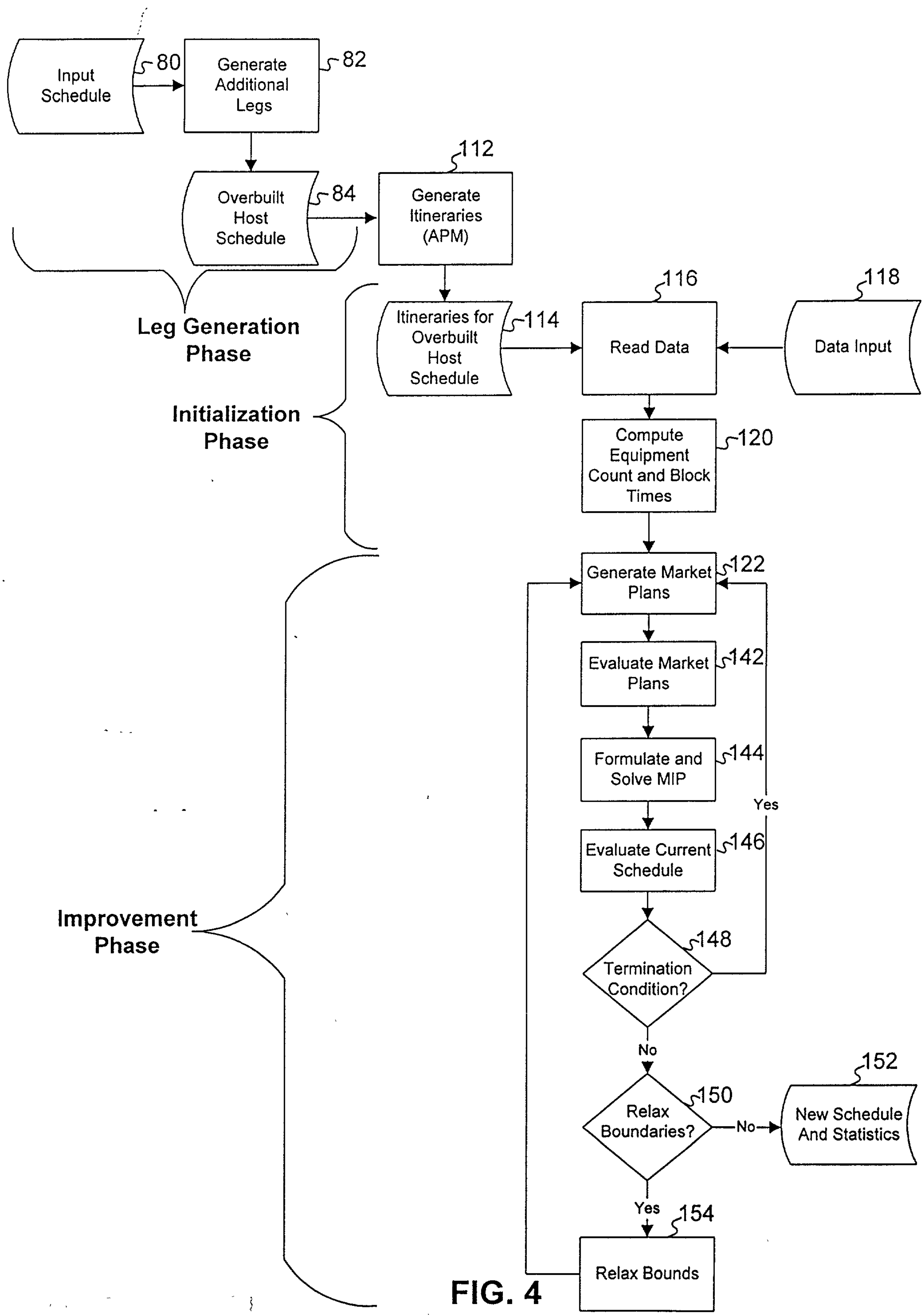
Input Schedule
80
Generate Additional Legs
82
Overbuilt Host Schedule
84
Leg Generation Phase
112
Generate Itineraries (APM)
Itineraries for Overbuilt Host Schedule
114
116
Read Data
118
Data Input
Initialization Phase
Compute Equipment Count and Block Times
120
Generate Market Plans
122
Evaluate Market Plans
142
Formulate and Solve MIP
144
Yes
Evaluate Current Schedule
146
Improvement Phase
Termination Condition?
148
No
Relax Boundaries?
150
No
New Schedule And Statistics
152
Yes
154
Relax Bounds

FIG. 4

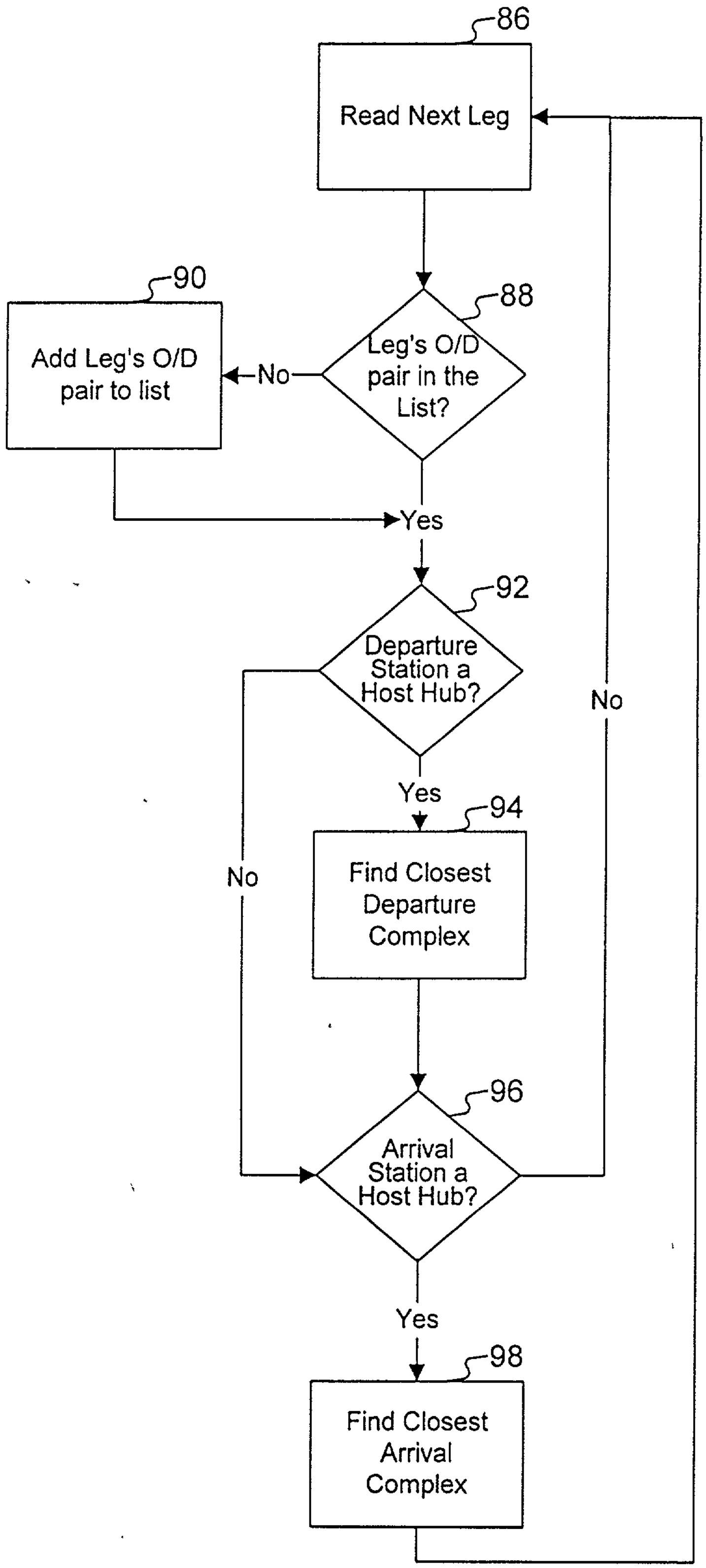
86
Read Next Leg
90
Add Leg's O/D pair to list
88
Leg's O/D pair in the List?
No
Yes
92
Departure Station a Host Hub?
No
Yes
94
Find Closest Departure Complex
96
Arrival Station a Host Hub?
No
Yes
98
Find Closest Arrival Complex

FIG. 5

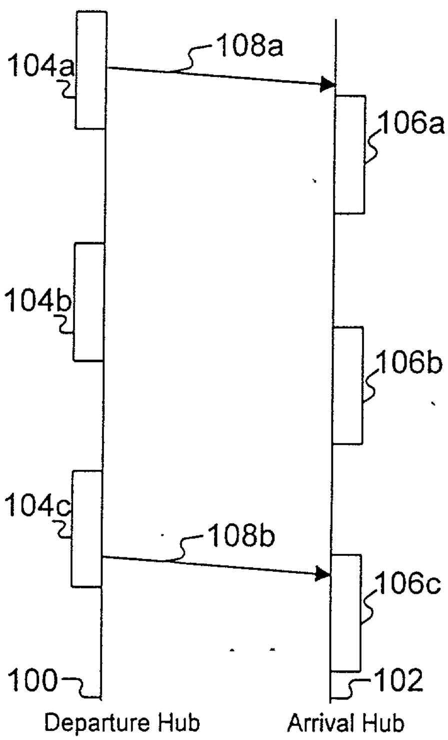

FIG. 6A

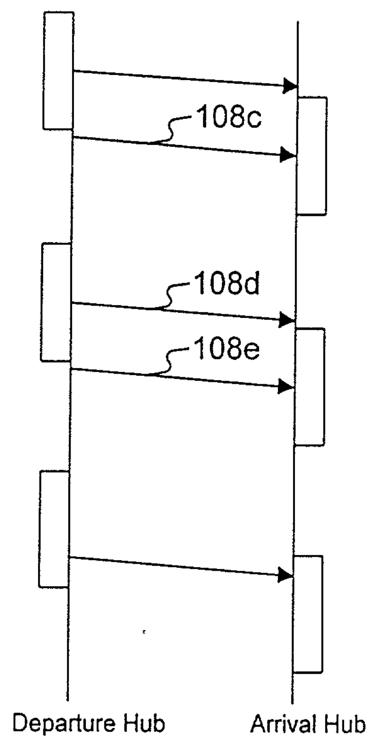

FIG. 6B

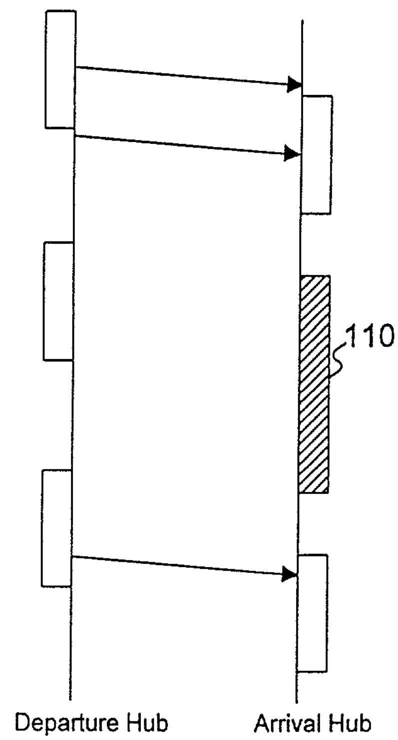

FIG. 6C

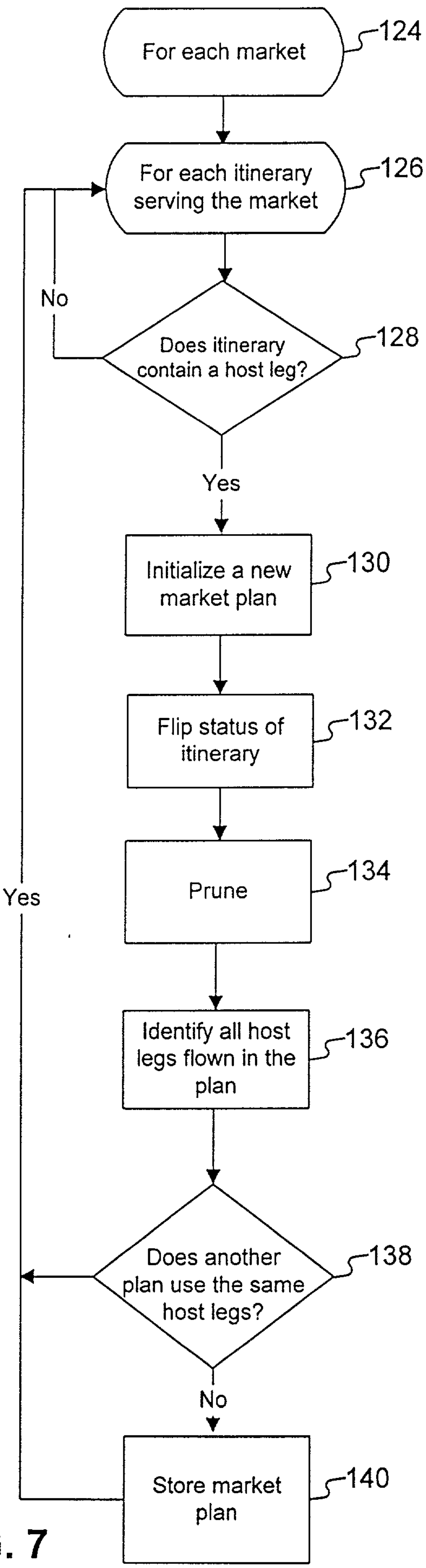
For each market
124
For each itinerary serving the market
126
No
Does itinerary contain a host leg?
128
Yes
Initialize a new market plan
130
Flip status of itinerary
132
Prune
134
Identify all host legs flown in the plan
136
Yes
Does another plan use the same host legs?
138
No
Store market plan
140

FIG. 7

APPENDIX A (FEASIBILITY MODEL)

$$\text{Minimize} \sum_{q \in Q} \sum_{s \in S} \sum_{t \in T(q,s)} b^{+}(q,s,t) - b^{-}(q,s,t)$$

Subject to

$$\sum_{l \in L_{in}(q,s,t)} \delta_l - \sum_{l \in L_{out}(q,s,t)} \delta_l + GroundArc(q,s,\mathrm{Pr}\,ev(t)) - GroundArc(q,s,t) =$$

$$b^{+}(q,s,t) - b^{-}(q,s,t), \forall (q,s,t) \in Q \times S \times T$$

$$Balance(q,s,t) = b^{+}(q,s,t) - b^{-}(q,s,t), \forall (q,s,t) \in Q \times S \times T$$

Variables

$b^{+}(q,s,t) \geq 0, \forall (q,s,t) \in Q \times S \times T$, INTEGER

$b^{-}(q,s,t) \geq 0, \forall (q,s,t) \in Q \times S \times T$, INTEGER

$Balance(q,s,t)$ INTEGER

$\mathrm{GroundArc}(q,s,t) \geq 0, \forall (q,s,t) \in Q \times S \times T$, INTEGER

Parameter/Set	Source	Description
Q	Input from input schedule	Set of all equipment types.
S	Input from input schedule	Set of stations that are or could be operated by host airline.
$T^{QS}(q,s)$	Identified when formulating the feasibility model.	All points in time at which a flight using equipment q can depart from or land at station s.
δ_l	From input schedule.	0/1 indicator: 1, if leg l is flown in the original input schedule; 0 otherwise.

Table 1 Parameters used in Feasibility Model (Appendix A).

Variable	Type	Description
b+(q,s,t)	Integer >= 0	Number of planes of type q that go into service at station s at time t.
b-(q,s,t)	Integer >= 0	Number of planes of type q that are taken out of service at station s at time t.
GroundArc(q,s,t)	Integer >= 0	Number of planes of type q that remain on the ground at station s after the departure/arrival that take place at time t.
Balance(q,s,t)	Integer >= 0	Number of planes of type q that go into service or are taken out of service at station s at time t.

Table 2 Variables used in Feasibility Model (Appendix A).

APPENDIX B (Market Plan Selection Model)

Maximize $TotalRevenue - TotalSpillCost - TotalPaxCost - TotalStationCost - TotalLegCost$

Subject to

$$TotalRevenue = \sum_{p \in P} PlanRev(p)\ Plan(p)$$

$$TotalSpillCost = \sum_{l \in L} SpillCost(l)\ Spill(l)$$

$$TotalPaxCost = \sum_{l \in L} PaxCost(l)\left(Capacity(l) - Spoil(l)\right)$$

$$TotalStationCost = \sum_{s \in S} StationCost(s)\ Station(s)$$

$$TotalLegCost = \sum_{l \in L, q \in Q^L(l)} LegCost(l,q) Equipment(l,q)$$

$$\sum_{l \in L_{in}^{QST}(q,s,t)} Equipment(l,q) - \sum_{l \in L_{out}^{QST}(q,s,t)} Equipment(l,q) + GroundArc(q,s,prev(t)) - GroundArc(q,s,t)$$

$$= \mathrm{Balance(q,s,t)}, \forall \mathrm{(q,s,t)} \in \{\mathrm{Q \times S \times T}\}$$

$$\sum_{l \in \mathrm{Re}\,dEye(q)} Equipment(l,q) + \sum_{(s,t) \in S \times T^S(s): t = last(T^S(s))} GroundArc(q,s,t) \le PlaneCount(q), \forall q \in Q$$

$$\sum_{l \in L^Q(q)} Equipment(l,q)\ BlockTime(l) \le BlockTime(q), \forall q \in Q$$

$$\sum_{l \in L_{out}^S(s)} Leg(l) \ge MinOpp(s)\ Station(s), \forall s \in S$$

$$\sum_{l \in L_{out}^S(s)} Leg(l) \le Station(s)\ M, \forall s \in S$$

$$\sum_{l \in L_{out}^S(s)} Leg(l) \le MaxOpp(s), \forall s \in S$$

$$\sum_{l \in L^{SI}(svc)} Leg(l) \le Service(svc)\ M, \forall svc \in S$$

$$\sum_{l \in L^{SI}(svc)} Leg(l) \geq MinSvcFreq(svc) Service(svc), \forall svc \in SI$$

$$\sum_{l \in L^{SI}(svc)} Leg(l) \leq MaxSvcFreq(svc), \forall svc \in SI$$

$$\sum_{q \in Q^{L}} Equipment(l,q)\ Size(q,l) = Capacity(l), \forall l \in L$$

$$\sum_{p \in P^{L}(l)} Demand(l,p)\ Plan(p) = Capacity(l) + Spill(l) - Spoil(l), \forall l \in L$$

$$\sum_{p \in P^{M}(m)} Plan(p) = Market(m), \forall m \in M$$

$$\sum_{p:l \in p} Plan(p) \leq Leg(l), \forall l \in L$$

$$\sum_{q \in Q^{L}(l)} Equipment(l,q) = Leg(l), \forall l \in L$$

$$Market(m) \geq RequiredMarket(m), \forall m \in M$$

$$Service(si) \geq (1 - ThresholdSvcFreq(si)), \forall si \in SI$$

$$Station(s) \geq (1 - ThresholdOPP(s)), \forall s \in S$$

$$Leg(l) \geq RequiredLeg(l), \forall l \in L$$

Variables

$TotalRevenue \geq 0$

$TotalSpillCost \geq 0$

$TotalPaxCost \geq 0$

$TotalStationCost \geq 0$

$TotalLegCost \geq 0$

$Plan(p) \in [0,1], \forall p \in P$

$Leg(l) \in \{0,1\}, \forall l \in L$

$GroundArc(q,s,t) \geq 0, \text{INTEGER}, \forall (q,s,t) \in Q \times S \times T$

$Equipment(l,q) \in \{0,1\}, \forall (l,q) \in L \times Q^{L}(l)$

$Spill(l) \geq 0, \forall l \in L$

$Spoil(l) \geq 0, \forall l \in L$

$Capacity(l) \geq 0, \forall l \in L$

$Service(svc) \in \{0,1\}, \forall svc \in SI$

$Market(m) \in \{0,1\}, \forall m \in M$

$Station(s) \in \{0,1\}, \forall s \in S$

Parameter/Set	Source	Description
P	Input from generate market plans	Set of all market plans
S	Derived from overbuilt schedule.	Set of all stations.
$T^S(s)$	Derived from overbuilt schedule.	Set of all points in time at which an arrival or departure can occur at station s.
M	User input.	Set of all markets.
$P^M(m)$	From generate market plans.	Set of all plans for market m.
$\text{Redeye}(q)$	Identified when formulating the MIP	Set of all Equipment(l,q) variables that are associated with a flight over midnight.
L	From overbuilt schedule.	Set of all flight legs.
$Q^L(l)$	From user input and input schedule.	Set of all equipment types that can be used on leg l.
$L_{in}^{QST}(q,s,t)$	Identified when formulating the MIP.	Set of all flights that can use equipment q and that arrive at station s at time t.
$L_{out}^{QST}(q,s,t)$	Identified when formulating the MIP.	Set of all flights that can use equipment q and that depart from station s at time t.
$L^Q(q)$	Identified when formulating the MIP.	All flight legs that can use equipment q.
$L_{in}^S(s)$	Identified when formulating the MIP.	All flight legs that arrive at station s.
$L_{out}^S(s)$	Identified when formulating the MIP.	All flight legs that depart from station s.
$L^{SI}(svc)$	Identified when formulating the MIP.	All flight legs that belong to service svc.
$P^L(l)$	Identified when formulating the MIP.	All market plans that contain leg l.
$T^{QS}(q,s)$	Identified when formulating the MIP.	All points in time at which a flight using equipment q can depart from or land at station s.
PlanRev(p)	Input from APM	Revenue of market plan p.
SpillCost(l)	Input from APM	Estimated lost revenue of not accommodating (spilling) 1 customer on leg l.
PaxCost(l)	Input from APM	Cost of transporting one passenger on leg l.
StationCost(s)	Input from APM	Cost of operating station s.
LegCost(l,q)	Input from APM	Cost of operating equipment q on leg l.
Size(q,l)	Input from APM	Number of seats of equipment q on leg l.
Demand(l,p)	Input from APM	Demand for leg l associated with market plan p.
BlockTime(l)	Input from user or input schedule	Time needed to fly leg l.
Balance(q,s,t)	Input from user or Feasibility model	Number of planes of type q on the ground at station s at time t
PlaneCount(q)	Input from user or Feasibility model	Number of available planes of type q.
BlockTime(q)	Input from user or Feasibility model	Total flying time available for type q.
MinOpp(s)	Input from user	Lower bound on origin point of presence at station s.
MaxOpp(s)	Input from user	Upper bound on origin point of presence at station s.
MinSvcFreq(si)	Input from user	Lower bound on service frequency for service si.

MaxSvcFreq(si)	Input from user	Lower bound on service frequency for service si.
RequiredMarket(m)	Input from user	(0/1) Indicator: 1, if market m must be served.
ThresholdSvcFreq(si)	Input from user	(0/1) Indicator: 1, if service si can be dropped.
ThresholdOPP(s)	Input from user	(0/1) Indicator: 1, if station s can be closed.
RequiredLeg(l)	Input from user	(0/1) Indicator: 1, if leg l has to be flown.

Table 1 Parameters used in Market Plan Selection Model (Appendix B).

Variable	Type	Description
TotalRevenue	Continuous >= 0	Total revenue of all selected market plans.
TotalSpillCost	Continuous >= 0	Lost revenue of passengers that can not be accommodated due to capacity limitations.
TotalPaxCost	Continuous >= 0	Total cost of transporting passengers.
TotalStationCost	Continuous >= 0	Total cost of operating all chosen stations.
TotalLegCost	Continuous >= 0	Total fixed operating cost of all selected flight legs.
Plan(p)	Continuous in (0,1)	Variable that indicates at what level plan p was selected.
Spill(l)	Integer >= 0	Number of passengers that could not be accommodated on leg l.
Capacity(l)	Integer >= 0	Capacity assigned to leg l.
Spoil(l)	Integer >= 0	Number of seats on leg l that can not be sold.
Station(s)	Binary	A value of 1 indicates that station s is operated; a value of 0 indicates that station s is closed.
Equipment(l,q)	Binary	The variable is equal to 1 if equipment q is flown on leg l; 0 otherwise.
Leg(l)	Binary	Has value of 1, if leg l is operated; 0 otherwise.
GroundArc(q,s,t)	Integer >= 0	Number of planes of type q that stay on the ground at station s at time t.
Service(svc)	Binary	Has value 1, if service svc is operated; 0 otherwise.
Market(m)	Binary	Has value 1, if market m is served; 0 otherwise.

Table 2 Variables used in Market Plan Selection Model (Appendix B).

Objective Function:
Maximize total revenue minus operating and spill cost.

Constraints:

Total revenue is equal to the sum over all market plans of market plan revenue times market plan valuation.

Total spill cost is equal to the sum over all legs of the number of spilled passengers on a leg times the cost of spilling a passenger on the leg.

Total passenger cost is equal to the sum over all legs of the number of passengers accommodated on a leg times the cost of transporting a passenger on the leg.

Total station cost is equal to the sum of operating all open stations.

Total leg cost is equal to the sum of the equipment specific fixed costs of all legs that are flown.

Node Balance:
All planes that arrive at station s at time t or that are on the ground at station s at time t must right after time t either be on the ground right at station s or depart from station s.

Plane Count:
The number of planes of a given equipment type that are used in the schedule has to be less than or equal to the number of planes available for this equipment type.

Block Time:
The total flying time of all legs flown by a given equipment type must be less than or equal to the total flying time available for this equipment type.

Minimum Service Frequency:
If a service is operated then the service frequency must be greater than or equal to the user defined minimum service frequency for this service.

Maximum Service Frequency:
For each service, the frequency must be less than or equal to the user defined maximum service frequency for this service.

Minimum Origin Point of Presence:
If a station is operated then the number of flights departing from this station must be greater than or equal to the user defined minimum origin point of presence of this station.

Maximum Origin Point of Presence:
For each station, the number of flights departing from this station must be less than or equal to the user defined maximum origin point of presence of this station.

Station Opening:
A station must be operated if there is at least one flight arriving or departing from this station. The user specifies a set of stations that have to be operated.

Service Operation:
A service is considered as operated if at least one flight that belongs to the service is flown. The user specifies a set of services that have to be operated.

Leg Capacity:
The capacity of a flight leg is equal to the number of seats of the equipment assigned to the leg.

Demand:
The total demand for a flight leg is equal to the sum over all market plans that contain the leg of the market plan valuation times the demand associated with the leg in the market plan.

Spill and Spoil:
The demand for a flight leg is equal to capacity of the leg plus the number of spilled passengers minus the number of empty seats on the leg.

Market Plan selection:
The sum over all market plans that are selected at a fractional level for a given market is equal to one if service offered in the market and 0 otherwise. Service has to be offered in a market if the user requires it.

Equipment Assignment:
Exactly one equipment type is assigned to each flight that is flown. The user specifies a set of legs that have to be flown.